RF Exposure Analysis for Multiple Wi-Fi Devices In Enclosed Environment

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***Abstract*— Wi-Fi devices operated inside a metallic enclosure have been investigation in the recent years. A motivation for this study is to investigate wave propagation inside an enclosed environment such as elevator, car, aircraft, and spacecraft. There are performances and safety concerned that when the RF transmitters are used in the metallic enclosed environments. In this paper, the field distributions inside a confined room were investigated with multiple portable Wi-Fi devices. Computer simulations were performed using the rigorous computational electromagnetics (CEM). The method of moments (MoM) was used to model the mutual coupling among antennas. The geometrical theory of diffraction (GTD) was applied for the multiple reflections off the ground and walls. The prediction of the field distribution inside such environment is useful for the planning and deployment of a wireless radio and sensor system. Factors that affect the field strengths and distributions of radio waves in confined space were analyzed. The results could be used to evaluate the RF exposure safety in confined environment. By comparing the field distributions for various scenarios, it was observed that the Wi-Fi device counts, spacing and relative locations in the room are important factors in such environments. The RF Keep Out Zone (KOZ), where the electric field strengths exceed the permissible RF exposure limit, could be used to assess the RF human exposure compliance. As shown in this study, it's possible to maximize or minimize field intensity in specific area by arranging the Wi-Fi devices as a function of the relative location and spacing in a calculated manner.**

Keywords- RF exposure; metallic enclosure; Wi-Fi device; WLAN; Acess Point; Laptop; Tablet; Computational Electromagnetics.

I. INTRODUCTION

The use of Wi-Fi devices such as notebook computers, tablets, PDAs, and smart phones has grown rapidly in recent years. At the same time, the concern of the Radio-Frequency (RF) radiation effects on human health due to the Wi-Fi devices by the consumers has also increased. RF safety is an important issue for the Wi-Fi device manufacturers, consumers, and the government regulators.

The RF exposure standards on the permissible radiation levels of consumer Wi-Fi devices are regulated by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines and the IEEE C95.1 standard [1]. The Wi-Fi devices must be designed such that the radiated field strength from the Wi-Fi transmitter is within the permissible exposure limits. These permissible exposure limit standards are based on the thermal effects of the RF energy in the human body.

Wi-Fi devices operated inside a metallic enclosure have been investigation in the recent years [2-4]. A motivation for this study is to study wave propagation inside an enclosed environment such as elevator, car, aircraft, and spacecraft. The health risk could be higher for the RF transmitters, such as Wi-Fi devices, used in the confined environments. This concern is based on the fact that with small or no escape route for the RF energy, all energy emitted by the RF emitters will be absorbed by the passengers.

In the enclosed environment, the transmit power of some advanced smart Wi-Fi devices could automatically increase for compensating the poor reception of the received signals. Because of the wave reflections, electric field in enclosed environment could be very complicated with constructive and destructive interferences. The field strength could increase due to the multiple reflections.

There has been concern that a metallic enclosure could potentially act like an imperfect resonant cavity, leading to RF hot spots where the electromagnetic fields are enhanced [5,6]. This could increase the severity of the RF exposure for the Wi-Fi device usages in such an environment. The field distributions are expected to be significantly changed from an open space which is the interest of this study.

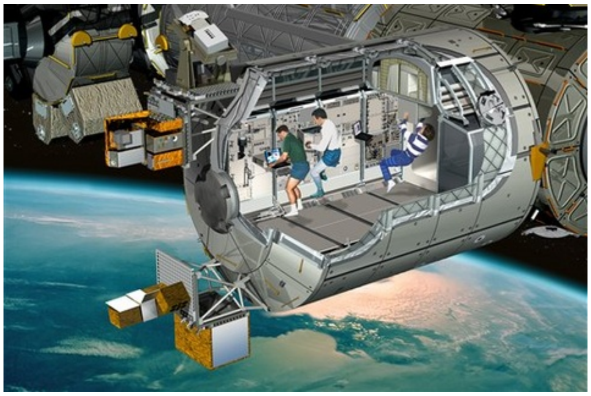

Figure 1. International Space Station consists many enclosed metallic modules.

The distribution of the electric field from the multiple Wi-Fi transmitters is calculated using the rigorous computational electromagnetics (CEM). The method of moments (MoM) was used to model the mutual coupling among antennas [7]. The geometrical theory of diffraction

(GTD) was applied for the multiple reflections off the ground and walls [8]. The RF Keep Out Zone (KOZ), where the calculated electric field strength exceeds the permissible RF exposure limit, could be determined to assess the RF human exposure compliance.

II. Simulation Results

The enclosed indoor environment is modeled, and a deterministic ray tracing algorithm-the geometrical theory of diffraction is used for the field interactions including multiple reflections from the ground and walls. The multiple Wi-Fi devices were modeled as half-wavelength dipole antennas placed at various separations from each other. The transmit power is assumed to be 0.25 W or 24 dBm which is typical for consumer Wi-Fi devices. An industrial, scientific and medical (ISM) radio frequency of 2.4 GHz is assumed. The antennas were modeled using the rigorous method of moments. The antenna mutual coupling effects were taken into account.

A. Confined Space

Figure 2 shows the field intensity for a Wi-Fi antenna (a) placed in an opened space (on the left) and (b) placed in a confined metallic room sized of 2 m by 2 m by 2 m (on the right). Figure 3 shows the field intensity for two Wi-Fi antennas (a) placed in an opened space (on the left) and (b) placed in a confined room sized of 2 m by 2 m by 2 m (on the right). The spacing between the Wi-Fi antennas is 2 wavelengths. Figure 4 shows the differences of the electric fields between in the confined space and in free space. For one Wi-Fi device is shown on the left and for two Wi-Fi devices is shown on the right. As can be seen, the field strengths could increase significantly for Wi-Fi device operated in a confined room than in an opened space. When the direct signal and the reflected signals are in phase, the total signals increased results from a constructive interference.

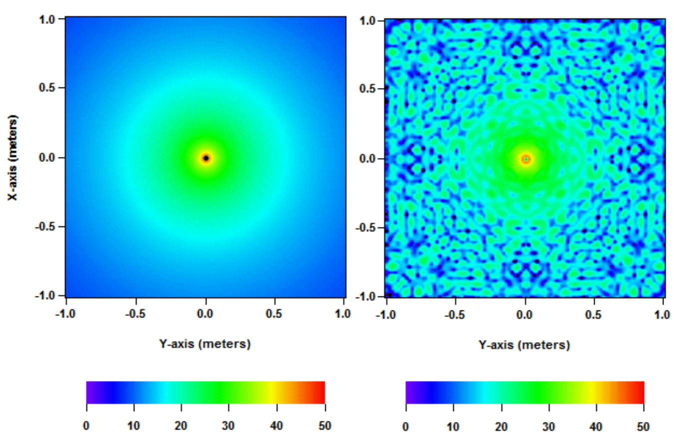

Figure 2. Electric field distributions for one Wi-Fi device in free space (Left) and in a confined space (Right).

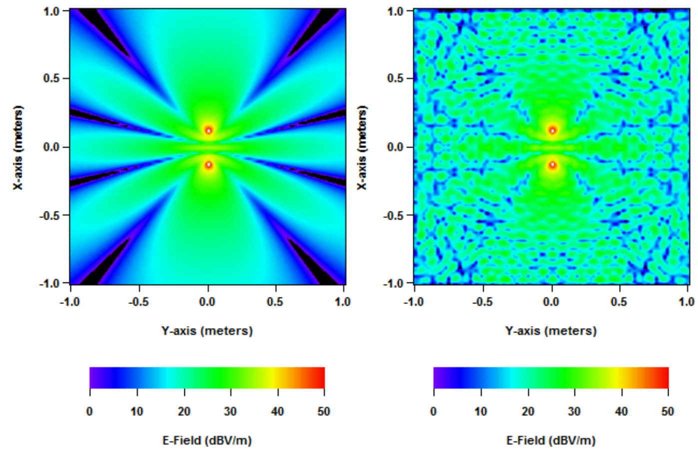

Figure 3. Electric field distributions for two Wi-Fi devices in free space (Left) and in a confined environment (Right).

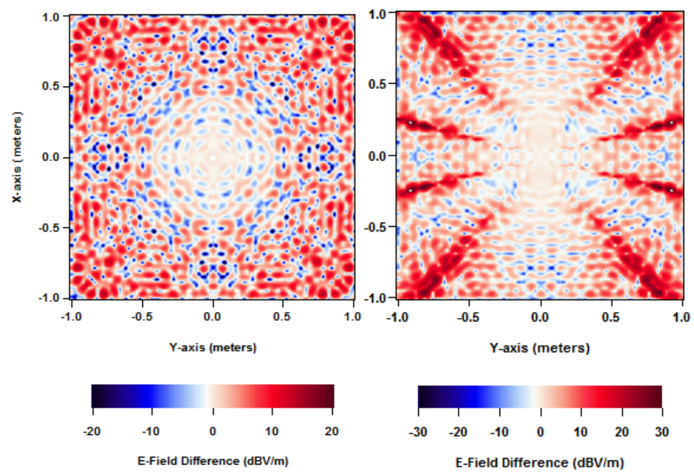

Figure 4. Differences of electric fields between in a confined space and in free space for one (Left) and two (Right) Wi-Fi devices.

B. Spacing Between Wi-Fi Devices

Figure 5 shows the field intensity for two Wi-Fi antennas placed 1 λ (Left) and 1.5 λ (Right) apart in a closed room sized, 2 m by 2 m by 2 m. Figure 6 shows the field intensity for three Wi-Fi antennas placed 1 λ (Left) and 1.5 λ (Right) apart. It can be observed that the field distributions are very different with different spacing among the Wi-Fi devices. The mutual coupling effects are determined by the antenna spacing. The RF energy radiation patterns (i.e., stronger in some directions) can be changed by varying the antenna spacing. Thus, the Wi-Fi device spacing has a large influence on the field distributions.

C. Number of Wi-Fi Devices

Figure 7 shows the electric field distributions for one (Left) and two (Right) Wi-Fi devices placed near the upper right corner of a confined room. As can be seen, the field strengths could increase significantly by adding multiple Wi-Fi devices. Figure 8 shows the electric field increased with multiple Wi-Fi devices as shown for two (Left) and four devices (Right). At some locations, as shown in blue spots, the fields are reduced. The reason is destructive interferences among the different electric field components with significant phase difference.

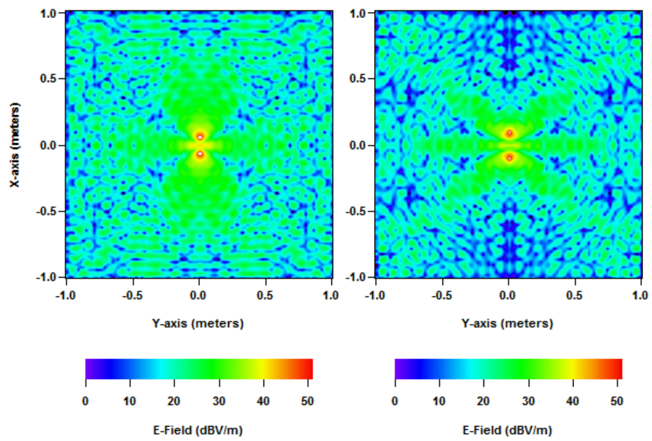

Figure 5. Electric field distributions for two Wi-Fi devices with 1 λ (Left) and 1.5 λ (Right) spacing.

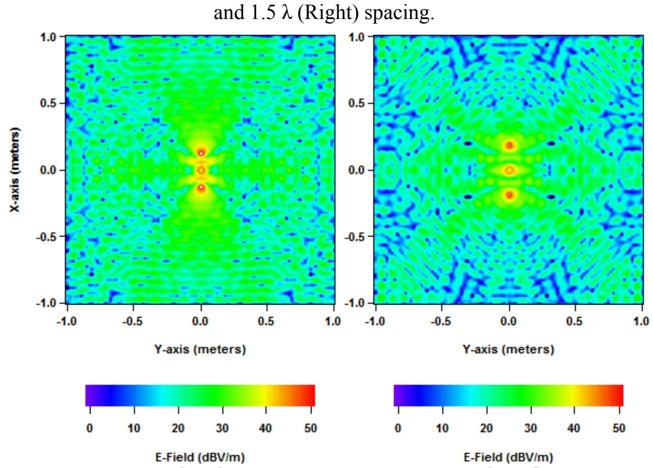

Figure 6. Electric field distributions for three Wi-Fi devices with 1 λ (Left) and 1.5 λ (Right) spacing.

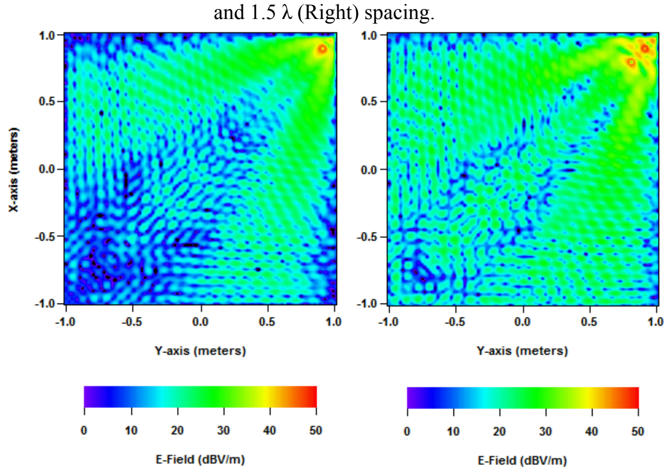

Figure 7. Electric field distributions for one (Left) and two (Right) Wi-Fi devices near the upper right corner.

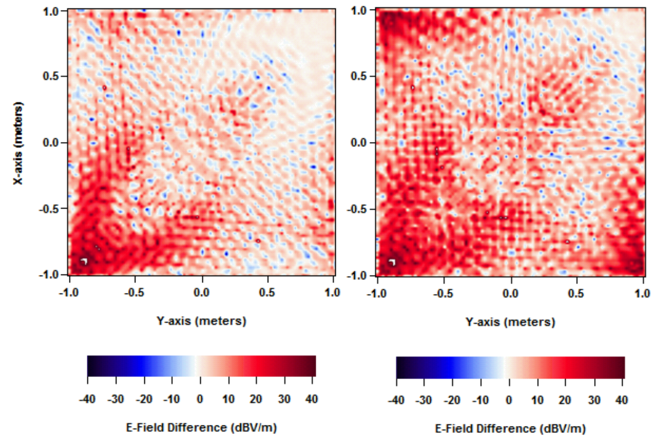

Figure 8. Electric field increases with multiple Wi-Fi devices as shown for two (Left) and four devices (Right).

D. *Locations of Wi-Fi Devices*

The Wi-Fi device locations could have large influence on the field distributions. As shown in Figures 9 and 10, the four Wi-Fi devices are placed near the center and placed near the corners.

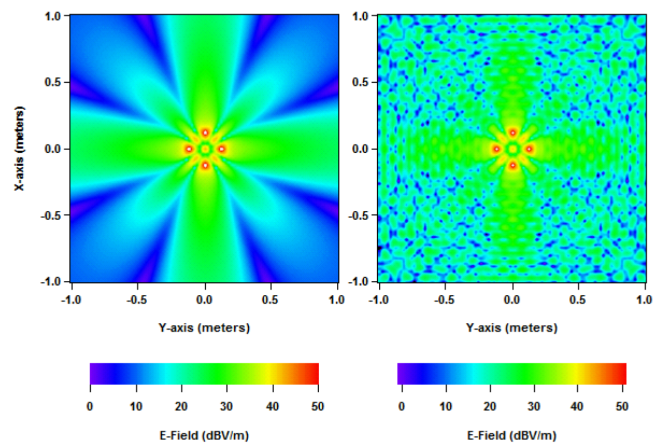

Figure 9. Electric field distributions for four Wi-Fi devices placed in free space (Left) and placed in a confined environment (Right) near the center.

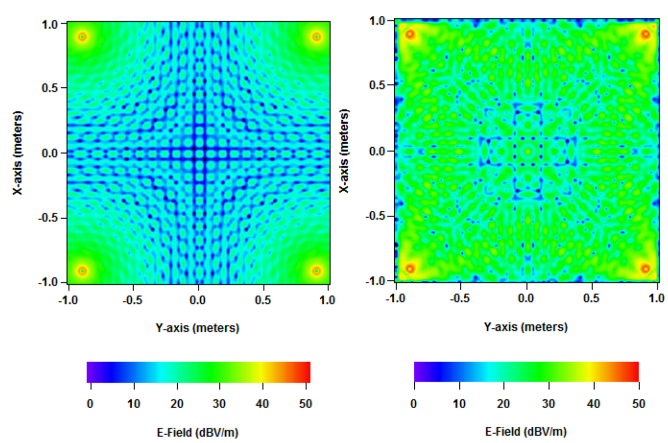

Figure 10. Electric field distributions for four Wi-Fi devices placed in free space (Left) and placed in a confined environment (Right) near the corners.

III. CONCLUSION

A numerical study on RF radiation of multiple Wi-Fi devices inside a confined space is presented in this paper. The effects of number of Wi-Fi devices and their positions inside the room on the electric field intensities and distributions were investigated. Results have shown that the electric field could be significantly affected by the location and the number of the Wi-Fi devices. The electric fields are enhanced due to mutual coupling among the Wi-Fi devices and the multiple reflections from the ground and walls. No cavity or resonance effects were observed for the 2.4 GHz ISM band devices in the 2 m by 2 m by 2 m room with investigated placements. The resonance effects are likely requiring smaller confined space volume in coupling with lower frequency devices. As shown in this study, it's possible to maximize or minimize field intensity in specific area by arranging the Wi-Fi devices in a planned placement and spacing.

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